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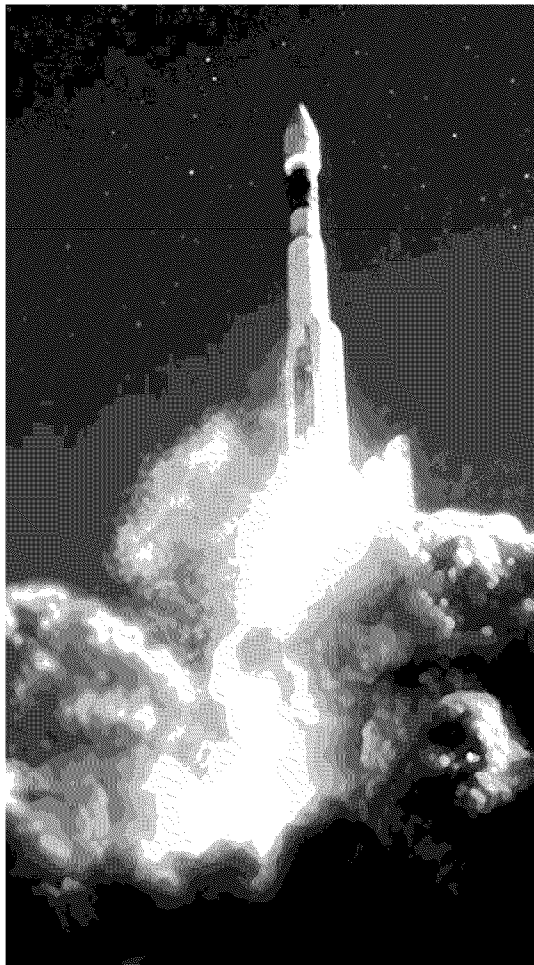
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The Evolved Expendable Launch Vehicle

Tough Decisions to Assure Access to Space

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Editorial Abstract: With the recent phaseouts of multiple medium/heavy space-launch vehicles, the evolved expendable launch vehicle (EELV) will soon become the nation's only vehicle able to insert capabilities into space and replenish them. However, the future EELV faces serious challenges. Major Wood contends that only a determined effort to maintain multiple providers, foster indigenous propulsion sources, and share civil-military technology will prevent potentially critical program delays and reduced effectiveness of space missions.



SINCE OPERATION DESERT STORM, the joint operational arena has recognized space as having vital strategic and tactical military significance. Assuring our access to space and having a responsive space-launch capability are key to success in all aspects of spaceborne operational capabilities, including communications, weather, navigation, positioning/timing, and intelligence, surveillance, and reconnaissance. With the recent phaseout of Atlas II/III, Titan II, and Titan IV, the evolved expendable launch vehicle (EELV) has already taken over for previous medium-through-heavy space lifters. The Air Force will fully transition from the last remaining “heritage” launch vehicle, the Delta II, following launch of the final global positioning system IIR satellite in 2008. The EELV will then become the nation’s only space enabler, assuring accurate placement of our critical space assets so they can provide new or augmented capabilities—or replenishment of current capabilities.

The US Space Transportation Policy of 6 January 2005 states that the United States “must maintain robust, responsive, and resilient U.S. space transportation capabilities to assure access to space [and that] for the foreseeable future, the capabilities developed under the Evolved Expendable Launch Vehicle program shall be the foundation for access to space for intermediate and larger payloads for national security, homeland security, and civil

purposes to the maximum extent possible.”¹ The EELV is part of a space-lift modernization program of the Department of Defense (DOD) whereby the government contracts for launch services from two providers: Boeing, which builds the Delta IV family of boosters, and Lockheed Martin, which builds the Atlas V family. This article summarizes the EELV program’s history and current status, introduces some program challenges to maintaining launch success and assured access, and provides recommendations to better support our war fighters.

Background and Program History

Based upon recommendations from the *Space Launch Modernization Study* (otherwise known as the Moorman Study), the National Space Transportation Policy of August 1994 directed the development and implementation of a plan for evolving current expendable launch systems.² Plan development took place in October of the same year, and Congress appropriated \$40 million for space-launch modernization. Following release of a “request for proposal” in May 1995, Lockheed Martin and McDonnell Douglas (now the Boeing Company) were selected in December 1996 to continue with the preengineering and manufacturing-development-studies phase, each receiving \$60 million to refine its concepts. The intent called for selecting one provider that better met the goal of reducing launch costs by at least 25 percent while meeting requirements for war-fighter operability.

In November 1997, the Air Force foresaw what it considered a dramatic increase in the commercial-launch market. The service believed that both the commercial-launch industry and the government would benefit from developing a partnership whereby the government would spend less money to purchase launch services, while launch contractors would have permission to sell their services in the commercial marketplace to make up for—and perhaps exceed—the difference in revenue. Contractors would invest their own resources for design, manufacturing, and launch infra-

structure and would lease launchpads as well as facilities from the government. Therefore, instead of awarding a \$1.6 billion contract to one EELV contractor, the government awarded two separate contracts, each for an initial investment of \$500 million, to Lockheed Martin and Boeing in June 1998. Boeing would conduct 19 launches for \$1.38 billion, and Lockheed Martin nine launches for \$650 million.

Under this new partnership, the Air Force began purchasing launch services instead of actually taking possession of launch vehicles. The government now pays a contractor to place the payload in a specified orbit rather than actually buying flight hardware. Additionally, instead of operating launchpads and supporting facilities, it leases them to launch-service providers responsible for day-to-day operations even though the facilities reside on Air Force bases.

This arrangement, which represents a dramatic shift in the conduct of the launch business, produced effects felt throughout Air Force Space Command (AFSPC). The Air Force moved from the traditional role of contractor oversight to a new concept of insight into contractors’ processes. The act of taking a step back from the launch process and leaving details of daily operations to the launch providers has considerably restricted—in some areas removed—the government’s control over this process. Mandatory inspection points during booster production disappeared since the Air Force no longer bought the hardware, and AFSPC saw its role at the launch sites diminished. Oversight of hardware and protection of launchpad resources no longer resided with the launch squadrons.

Vehicle Families

The Atlas V and Delta IV each comprise a family of standardized, modularly designed launch vehicles configured to carry medium-to-heavy payloads to a variety of low Earth, polar, medium Earth, geostationary/geosynchronous, and geosynchronous transfer orbits (GTO). We have chosen these vehicles to optimize the positioning and availability of each of our critical defense payloads (fig.).

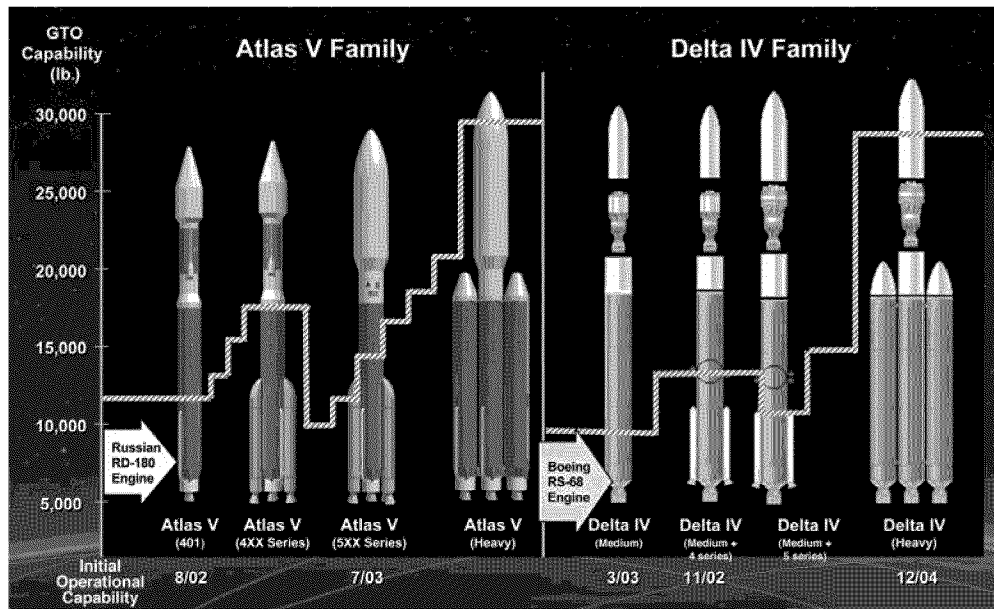


Figure. Atlas V and Delta IV families. (Courtesy AFSPC/PA.)

Note: The “stair-step” represents capabilities of different vehicle configurations using varied numbers of strap-on, solid-fuel rocket motors.

Atlas V

The Atlas V family, built by Lockheed Martin and operated by International Launch Services, evolved from the company’s experience with both the Atlas II/III and Titan II/IV programs into a commercial and government launch system for the twenty-first century. The Atlas III served as a technology test bed for the future Atlas V technologies, primarily the Centaur upper stage and the Russian-built RD-180 first-stage engine. The medium-through intermediate-class vehicles in the family use a single-stage Atlas main engine—the RD-180—and the newly developed common booster core (CBC) with up to five strap-on, solid-fuel rocket boosters. The booster uses liquid oxygen and RP-1 (rocket-grade kerosene) propellants. The Atlas V has a 4.57-meter-diameter composite payload fairing; it can also use the heritage Atlas II/III payload fairings. The Atlas V 500 series will use three configurations. A stretched configuration will support larger

payloads if Lockheed Martin develops an Atlas V heavy-vehicle configuration to carry the largest payloads to orbit.

The Atlas V Centaur upper stage uses a pressure-stabilized propellant-tank design using cryogenic propellants. Usually powered by one Pratt and Whitney RL 10A-4-2 engine with 22,300 pounds of thrust, the Centaur can accommodate two engines mounted on the second stage if required. The engines are capable of multiple in-space starts, which permit insertion into low-Earth parking orbit followed by a coast period and then insertion into GTO.

The Russian AN-124-100 aircraft transports the Atlas V boosters (manufactured in Waterton, Colorado, as is the Centaur upper stage) to the launch base. Atlas V currently launches from Space Launch Complex (SLC) 41 at Cape Canaveral Air Force Station, Florida, with a planned first flight from SLC 3E at Vandenberg AFB, California, in 2006. All variants of the Atlas V medium and intermediate launch

vehicles can launch from the same pad. Although Lockheed Martin has designs for the Atlas V heavy, it has received no orders for it to date and has produced no flight hardware.

Delta IV

The Delta IV family, built by Boeing and sold by Boeing Launch Services, is designed for optimum performance in a wide range of flight profiles and can carry payloads up to 29,500 pounds to GTO. The Delta IV partly evolved from the Delta III launch system that flew three times in the late 1990s and demonstrated the second stage now flown on Delta IV. Each Delta IV configuration maximizes the use of common hardware; combines highly reliable, flight-proven systems; incorporates the latest technology; and uses a single CBC—except the heavy, which utilizes three. Furthermore, all but the heavy can be augmented by two or four 1.5-meter-diameter strap-on, solid-fuel, graphite-epoxy motors. The booster main engine, a Rocketdyne RS-68 liquid-hydrogen/liquid-oxygen engine producing 663,000 pounds of liftoff thrust, mounts to the CBC first-stage structure. The fact that it has significantly fewer parts than older engine designs simplifies manufacturing and increases reliability.

The cryogenic second stage incorporates the Delta II's guidance system and the Pratt and Whitney RL-10B-2 engine. All Delta IV vehicles use the same RL-10B engines and fly using a second stage either four or five meters in diameter. Similarly, the vehicle can fly with either a four- or five-meter payload fairing to accommodate a wide variety of payloads. Ships transport the Delta IV, manufactured in Decatur, Alabama, to SLC 37 at Cape Canaveral and SLC 6 at Vandenberg. All Delta IV vehicle variants for the medium, medium-plus, and heavy vehicles can launch from the same pad.

Current and Future Challenges

As the EELV becomes the sole space-launch vehicle for the Air Force, the program faces a number of operational, technical, and programmatic challenges. The original EELV vi-

sion called for a government-commercial partnership to develop and operate an efficient, reliable, and cost-effective expendable launch vehicle to meet our nation's needs. This partnership would produce a robust US commercial launch capability that would handle government payloads safely and effectively; it would also develop a family of vehicles that would reduce launch costs by 25–50 percent yet support a robust commercial launch capability for both providers. The commercial space-launch market collapsed shortly after the Air Force's decision to retain two providers, however, making it very difficult for both to remain financially solvent. The cut-rate prices that the Air Force enjoyed in the 1998 competition are not available for future purchases of launch services. At nearly the same time, the policy of assured access to space through two families of launch vehicles emerged. The United States learned an important lesson about putting all of its eggs in one basket in the late 1980s with the two-and-one-half-year grounding of all DOD space launches following the loss of the *Challenger* space shuttle. Failures of three heavy-lift missions in 1998–99 and recognition of critical capabilities enabled from space further amplified the need for space access. As a result, the Air Force finds that its EELV program has become an “anchor tenant” for the Lockheed Martin and Boeing launch systems. The president's budget for fiscal year 2006 as well as the National Security Space Policy demonstrated the Air Force's support of assured access to space through two families of launch vehicles through 2010. Although the service requested significant EELV budget increases, undoubtedly at the expense of other capabilities, the continued expense of maintaining two providers leads many people to argue in favor of downselecting to just one.

These incredibly complex vehicles and their supporting infrastructure depend upon a very specific engineering, operations, and maintenance skill set, making space lift quite expensive in comparison to many other DOD activities. Nevertheless, this country simply cannot afford to sacrifice space support of frontline war fighters. We must maintain this

baseline workforce and the experience it brings or risk losing key strategic and tactical advantages over our adversaries.

This leads us to continue to try to eliminate any single points of failure in our launch programs. First among these is our requirement to maintain two providers. Several other issues also contribute to concerns over maintaining assured access to space. For example, the Atlas V family currently uses a Russian-built main engine, which brings with it obvious concerns over supply-line issues for DOD payloads. Additionally, both the Atlas V and Delta IV families rely upon variants of the same RL-10 second-stage engine, which represents yet another potential single point of failure for the DOD's entire space-launch program.

Two Providers

The Air Force must accept the cost of maintaining two launch providers; otherwise, we will face another scenario like the one we experienced after the *Challenger* accident in 1986. This comes at a cost of nearly \$1 billion annually, but it is a burden we must bear. Within the next five to seven years, current plans call for the phaseout of both the Delta II family and the space shuttle. Although the National Aeronautics and Space Administration (NASA) plans to bring a new shuttle-derived capability online in that time frame, this remains in the conceptual phase; we cannot leverage our nation's ability to reach space on a new, undeveloped program and its anticipated schedule. The EELV will be the DOD's only means of accessing space. Additionally, NASA is designing its vehicle to a very specific set of requirements focused on exploration rather than EELV-like payload-delivery needs. The new NASA vehicle will not serve as a viable alternative for most, if not all, DOD requirements. Thus, dropping to a single provider would unquestionably result in putting all of our eggs in one basket again. We do everything possible to guarantee mission success, but the harsh reality of space launch is that accidents have occurred in the past and will happen again, leading to at least a temporary grounding of an entire vehicle family. Under

a single-provider approach, this will result in a complete, likely extended, grounding of all launch capability throughout the DOD. Both the Air Force and the DOD have made financial decisions by asking how they could save money today and in the near term. We need to base funding decisions for this program not upon a traditional approach but upon a mature, longer-reaching one that takes into account the unacceptable ramifications of this country's losing military access to space.

Both Lockheed Martin and Boeing have proposed a merger to form a joint operation called United Launch Alliance (ULA), which has not received approval at the time of this writing. Contractor-provided estimates show a potential savings to the government of over \$100 million annually through efficiencies gained. The basic construct of the ULA would move both Atlas V and Delta IV production under the same roof in Boeing's Delta facility in Decatur and would locate engineering and management at Lockheed Martin's Atlas facility in Denver. The ULA construct does not represent a drawdown to a single vehicle family; rather, it provides for synergies between the two. As proposed under this alliance, both the Atlas V and Delta IV families would continue production. Assuming the contractor savings estimates—not yet validated by the Air Force—are accurate, this proposal could significantly decrease the cost of maintaining two separate providers and avoid the post-*Challenger* scenario mentioned above. Even with two providers, we must still address a variety of issues in order to guarantee our access to space: the need for a purely American industrial base, new upper-stage technologies, more responsive launch capability, and the possibility of partnering and sharing technology and costs with NASA.

RD-180 Coproduction

An agreement between NPO Energomash and Pratt and Whitney Rocketdyne, two leading Russian and American rocket-engine manufacturers, will eventually allow production of the Atlas V's Russian-made RD-180 main engine in the United States, assuming the availability

of funding to support the effort. Operation of a US coproduction facility will not begin until 2008, and the first launch using a coproduced engine may not occur until 2012. Any delays in coproduction will prolong US dependence upon Russian-built engines to launch vital DOD payloads. Under current restrictions of the International Traffic on Arms Regulations, it is difficult for the Air Force to gain the same in-depth understanding of engine design and test questions as it has with American-built engines used on other launch vehicles.

However, one might reasonably ask whether having the first-stage engine made in the United States is worth the start-up cost and risk of switching to this "new" one. Moreover, is it worth having an industry partner build a multi-hundred-million-dollar factory to produce engines that will see use only on Air Force/National Reconnaissance Office launches for the last seven years of the program (from 2013 to 2020)? The answer is a resounding yes. Again, this requires us to step back and make a longer-term funding commitment. In all likelihood, the EELV will continue to fly long beyond its originally projected phaseout in 2020. At some point, NASA's new launch vehicle will have matured and may be able to provide a viable backup to certain DOD launch requirements. Although likely capable of lifting large payloads into low Earth orbit, it would remain impractical for launches to GTO—a capability probably at least 10 years down the road. Once this happens, reliance upon a single provider may make sense if the Air Force is willing to accept a certain level of risk for its missions to geosynchronous Earth orbit.

Imagine a downselect occurring today, leaving us with only the Atlas V family and no capability to launch our payloads from the United States without relying upon a foreign-built engine. Having no inherent ability to build its own engines or troubleshoot production problems, the DOD would become solely reliant upon a Russian manufacturer to guarantee our access to space. Any issues with supply, production, or reliability would ground the fleet. In addition, reliance upon foreign-built engines greatly decreases the United States' baseline workforce in this highly spe-

cialized field. During the 1960s through 1980s, our workforce gained an immense amount of knowledge and experience from the Apollo, shuttle, and expendable-launch-vehicle programs. That aging workforce is now retiring; nevertheless, launch requires a highly specialized skill set. After losing an experienced workforce to retirement, potentially exacerbated by reliance on foreign manufacturers, America will find itself devoid of the required infrastructure to support its own access to space. Thus, we must fund coproduction of the RD-180 in the near term not only to protect our access to space, but also to protect our nation's baseline technological and production infrastructure in order to build the experience we need for future programs.

RL-10 Upper Stage

Propulsion remains the principal cause of launch failures. Unsurprisingly, most efforts to ensure access to space focus on the engines used on the EELV. Unlike the first-stage engines found on the Delta IV (RS-68) and Atlas V (RD-180), the engine used on both EELV second stages is based upon a single design.

The Pratt and Whitney RL-10 liquid-fueled rocket engine has served the United States as the hydrogen-fueled upper-stage propulsion system for over 40 years. Providing access to space for the Air Force by powering both EELV vehicles, the engine has seen its thrust level upgraded significantly in the last 15 years from 16,500 pounds to 24,750 pounds. The increase in power has resulted in a reduction in the structural and thermal margins of the engine's components, leaving it susceptible to manufacturing variations. We can attribute flight failure of a Delta III's RL-10 in 1999 to a poor brazing process in fabrication of the combustion chamber. Clearly, we could gain considerable benefits by investing in improvements to upper-stage propulsion.

Currently, AFSPC makes a yearly investment in improving the manufacturing, engineering, and reliability of the RL-10 engine. Such investment and the use of modern technology can yield engine reliability and marginal improvements in the near term. Specific

areas identified by the RL-10 community to enhance robustness include product, process, and inspection improvements. Even as work progresses on the existing engine design, there are concerns that we may have squeezed all the performance out of this system—that we are flying the engine at the edge of the envelope.

Alternatively, a clean-sheet approach would yield a new engine with modern manufacturing techniques and ample margin for the future. In preparation, we need to identify technology investment that can increase reliability and reduce risk to future programs. The Air Force's space program should invest in the future of upper-stage propulsion, both short and long term. Maintaining the status quo will not achieve and maintain reliable access to space.

Obviously, coproduction of the RD-180 and enhancements to or replacement of the RL-10 program reflect fixes to specific concerns. Several options exist for less specific but broader solutions, including a "rolling booster" and a potential partnership with NASA to explore emerging technologies as that agency pursues its own next-generation technologies.

Rolling Booster

Currently the DOD must purchase an EELV booster two years prior to an anticipated launch date to allow for production and launch-site processing. The rolling-booster concept, however, would posture the Air Force to launch a given payload on demand, enabling a more responsive capability since the government would place an advanced order for a generic vehicle from each launch provider. Rather than order this vehicle and set it aside, we would use the first one off the production line but retain a "spare" in the event we had need of a rapid launch, such as an expedited launch in time of crisis. Assuming we have built a payload and integrated it with the launch vehicle, the rolling-booster concept could possibly cut call-up times from two years to something on the order of days or weeks.

AFSPC attempted to fund this rolling-booster effort in the budget for fiscal year 2006, but at present, maintaining a spare booster in the contractor's inventory appears

cost-prohibitive. As payloads become more responsive and war-fighter needs for real-time augmentation of space assets emerge, the rolling booster will become a key enabler of America's assured access to space. Additionally, we have designed and integrated many of our critical payloads, such as the global positioning system, for launch on both the Atlas and Delta families. The rolling-booster concept provides significant flexibility for launch on demand, but many people view it as an unnecessary expense since a spare booster would likely cost in excess of \$50 million for each family. They should consider the fact that the DOD spends over \$1 billion annually to maintain our launch infrastructure and that this one-time purchase of "insurance" would represent only a small variation in that baseline. Furthermore, it would provide unprecedented operational flexibility for on-demand space support and guard against any potential grounding of a particular payload family. (A launch catastrophe or serious production issue by either provider grounds that vehicle family.) Rapidly moving a launch from one provider to the other would minimize or even negate the impact to war fighters in the field who rely upon precision navigation, intelligence, and communication capabilities from space.

DOD/NASA Partnership

In August 2005, the DOD and NASA committed to working together to assess and explore mutually beneficial technologies. They determined that "separating human-rated space exploration from unmanned payload launch will best achieve reliable and affordable assured access to space while maintaining our industrial base in both liquid and solid propulsion systems."³ Regarding the use and development of launch systems, the EELV is the vehicle of choice for missions of 11,000–44,000 pounds, which include intermediate and heavy payloads "for national security, civil, science, and International Space Station cargo re-supply missions."⁴ For missions of 25–30 metric tons, NASA will develop a crew-launch vehicle derived from the space shuttle's solid-fuel boosters and develop a new upper stage for human

spaceflight. For future moon missions, NASA plans call for development of a new launch vehicle in the 100-metric-ton class built from the shuttle's external tanks and solid rockets.

The Air Force and NASA will share a requirement for the EELV and face many of the same challenges posed by potential single points of failure. Current fiscal constraints prevent either agency from pursuing the types of technological advances that will likely be required in the future. This recent policy opens a variety of avenues for both to share the cost burdens associated with the needed technological advances, making continued assured access to space more affordable for them; however, time is of the essence.

The foremost of these opportunities concerns the second-stage engine described above. NASA must develop a new second stage for its proposed exploration efforts to the moon and Mars since the RL-10 is inadequate for its mission profiles. The flight regime for the DOD's Earth-orbiting payloads and that for a trans-lunar injection make it impossible for both agencies to use identical second stages because the thrust level required for NASA's missions far exceeds that required by the DOD. As recently as late 2005, NASA was considering pursuing new upper-stage technologies for this effort, creating potential cost sharing with the Air Force. But NASA changed paths in early 2006, deciding to use a new single upper-stage engine derived from the Saturn V J-2. Leveraging this existing technology will greatly reduce the timeline for NASA to return to the moon but leaves the Air Force with no easy way out of its reliance on the RL-10.

Clearly, the Air Force has already missed an outstanding opportunity to partner with NASA. Solely reliant upon the RL-10, the service will have to bear the full cost of eliminating this single point of failure. The merger of Rocketdyne and Pratt and Whitney in 2005 to form Pratt and Whitney Rocketdyne essentially eliminates competition in the private sector that might improve upon the RL-10 or decrease costs. Assuming that the ULA becomes a reality or that the Air Force is eventually forced to rely on a single launch provider, we will quickly find ourselves in a position in

which a sole-source commercial launch agency procures upper stages from a single manufacturer. Such a situation will remove any commercial incentive to improve engine technologies or decrease costs because the Air Force will have to meet the prices dictated. Obviously the Air Force and NASA must continue to look for synergies—but more in the realm of technology sharing than in common hardware. Research agencies within both organizations must poise themselves for cross talk. We have already missed a prime opportunity for partnering, and we must not let it happen again.

Conclusion and Recommendations

An ever-growing dependency on space requires us to provide a responsive means of assuring access to that medium. As our capabilities have evolved, we have experienced success with the two EELV families of launch services and expect much more in the future, with solid partnerships and a streamlining of our capabilities guaranteeing entry to space and ensuring that we meet our joint-service needs. Although both families, still in their infancy, reflect a natural evolution from our heritage system, they carry many risks. The DOD's current funding environment offers nothing extra for this or any other program. As the Air Force works hard to minimize costs while maximizing capability, the DOD must consider making a financial decision that is good for the short term; at the same time, it must avoid unacceptable risk to this nation's space-launch capability in the long term.

First and foremost, we must maintain two families of launch providers in the near term. Currently, the DOD has no payloads designed for or manifested on the space shuttle—we rely completely upon the EELV. Delta II will fly its last mission in 2008. At the time of this writing, the two providers have a total of only 11 EELV launches between them—not enough to instill the confidence required to justify a single launch provider in the near future. The rolling booster, a cheap insurance policy that allows flexibility in the near term as we con-

tinue to use new launch technologies, will provide responsiveness in the future as demand for real-time payload support continues to evolve, in sharp contrast to our current two-year call-up time.

Reliance upon a Russian-built engine is unacceptable. Instead, we should encourage the planned coproduction of the RD-180, which would allow us to use American technology to support DOD activities and minimize reliance upon foreign governments, all the while helping maintain a critical industrial baseline in the United States. Moreover, we must eventually replace the RL-10. Partnering with NASA on its emerging manned-exploration initiatives opens many doors for cost sharing and cooperative technological gains. We cannot stand by and watch any longer. The Air Force has already missed a prime opportunity and must now lean forward to share requirements,

funding, and technology for the benefit of both agencies.

None of this can happen without stepping back and taking a big-picture approach to our funding methodologies. Even though maintaining guaranteed access to space will require significant short-term costs, the longer-term expense of not maintaining this ability will prove far greater. Troops in the field will lose their current advantage over potential and current adversaries if we do not approach the EELV with a mature, life-cycle-oriented approach. We must maintain two providers, gain responsiveness through a rolling booster, establish an American baseline infrastructure, and aggressively engage with NASA to share technologies and approaches to develop commonality and synergies. Doing so will make both programs more cost-effective for the long haul. □

Notes

1. "Fact Sheet: U.S. Space Transportation Policy, January 6, 2005," n.p., <http://www.ostp.gov/html/SpaceTransFactSheetJan2005.pdf>.

2. *Space Launch Modernization Study* (Washington, DC: Department of Defense, 18 April 1994); and "Fact Sheet: National Space Transportation Policy" (Washington, DC: The

White House, Office of Science and Technology Policy, 5 August 1994), <http://www.ostp.gov/NSTC/html/pdd4.html>.

3. Ronald M. Sega and Michael D. Griffin to the Honorable John H. Marburger III, director, Office of Science and Technology Policy, letter, 5 August 2005.

4. Ibid.

The mission of the United States Air Force is to deliver sovereign options for the defense of the United States of America and its global interests—to fly and fight in air, space, and cyberspace.

—US Air Force Mission Statement